PRE-CAST CONCRETE SEGMENTAL ARCH DESIGN ON PILED FOUNDATIONS

Paul Proctor, Reinforced Earth Company Ltd., Truro, NS, Canada
Derek Essery, Reinforced Earth Company Ltd., Mississauga, ON, Canada
Bill Brockbank, Reinforced Earth Company Ltd., Mississauga, ON, Canada

ABSTRACT
The analysis of soil-structure interaction in concrete arch design has evolved considerably in past decades. With the advancement of numerical analysis design procedures, these types of structures can be accurately modelled to predict forces applied to the arch and underlying foundation.

This paper will demonstrate the effect on arch design that results with varying foundation soil stiffness and depth, for arches on a piled foundation. It will quantify moments and settlement that apply to specific arch designs.

Finally, the authors will illustrate a completed project incorporating TechSpan™ pre-cast concrete arch designed by Reinforced Earth Company Ltd. on a pile foundation as it relates to the analysis in this paper.

RÉSUMÉ
L'analyse de l'interaction structure-sol dans la conception des arches en béton a considérablement évolué depuis les dernières années. Avec l'amélioration des procédures de conception d'analyse numérique, ces modèles de structures peuvent exactement être modélisés afin de déterminer les différentes contraintes agissant sur l'arche ainsi que les réactions au sol de fondation.

Ce résumé démontrera les comportements de l'arche résultant de différents sols de fondation, de capacité portante et de profondeur, pour des arches appuyées sur une fondation de pieux. Il quantifiera les moments et les tassements appliqués précisément à la conception de l'arche.

Finalement, à l'aide d'un projet de la Société Terre Armée Ltée incorporant une arche en béton préfabriqué TechSpan appuyée sur une fondation de pieux, les auteurs illustreront leur méthode d'analyse et de modélisation.

1. INTRODUCTION

By using a Finite Element Method (FEM) design procedure, engineers can more accurately model the effects that applied loads have on buried structures when varying the strength and depth of their supporting foundations.

This paper will describe the type of buried structure used in the analysis, the approach using FEM design procedure, the effect of varying depth and quality of foundation soils for an arch on piles. A completed structure on a piled foundation will be illustrated as it relates to this paper with some concluding remarks.

2. GEOMETRIC CONFIGURATION

For the purposes of this analysis, the following configuration was used. TechSpan™ by Reinforced Earth Company Ltd. (RECO) is a pre-cast concrete segmental arch composed of two elements. It is designed using a three hinged configuration; two at the base and one at the crown. The arch dimensions used in this analysis are 18.0 m span x 7.5 m rise x 400 mm thick with 4.0 m of cover above the crown (see Figure 1). The soil and pile foundation depths are varied in the analysis, namely 5m, 10m and 15m. The directrix is the measured circumferential arc distance of the arch element (see Figure 2) The shape of the arch and the height of fill were selected to amplify the effects examined in this paper.

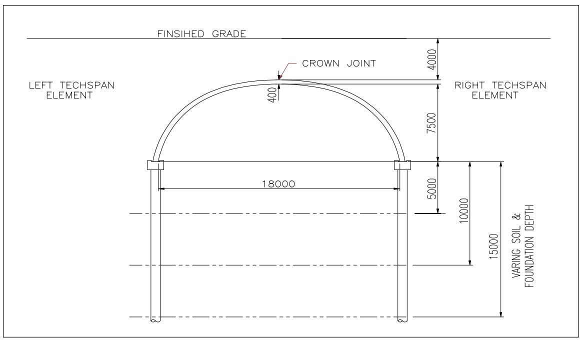

Figure 1. Arch Configuration

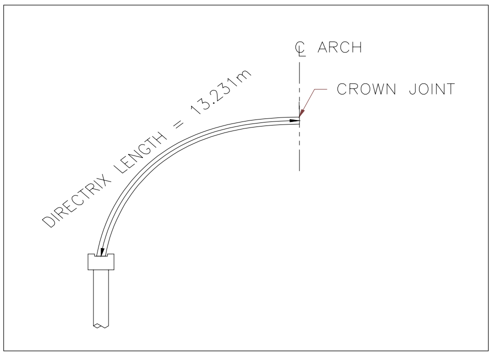

Figure 2. Arch Directrix

3. FINITE ELEMENT METHOD (FEM)

The state-of-the art design program developed by RECO call Aztech, uses a finite-element-method (FEM) to optimize the arch shape and minimize the bending moments in the concrete element sections. The pre-cast concrete elements are not rigidly connected to either the pile cap footings or to the adjacent element at the crown. This aspect enables the ends of the arch to act as pins or hinges, which do not transfer moment across the section. Effectively, applied moments are reduced resulting in a structure with significantly lower rebar quantities required.

Simplistically, the FEM design procedure is a nonlinear elasto-plastic program for the backfill with the foundation material and the arch analized as elastic elements as shown in Figure 3. The nonlinear stiffness matrices is solved by using the visco-plastic method, which is based directly on the initial strain method. The program applies loads during the backfilling operation in one meter increments alternating from one side to the other side of the arch until it reaches the finished grade elevation. At this point the program applies 10 kPa surcharge on the top lift. By using this procedure, the FEM program closely models the actual construction sequence.

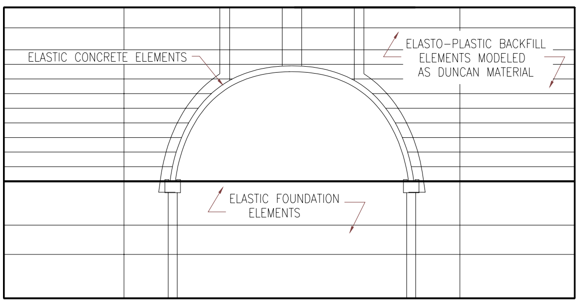

Figure 3. FEM Mesh Model

4. PURPOSE OF ANALYSIS

The purpose of this analysis is to examine the moments that occur in the arch on a pile foundation supported on various qualities of soil type and various depths.

5. PROPERTIES

The arch geometry and configuration is as shown in Figure 1.

Three soil types were chosen, Medium Dense Sand, Compact Silty Sand and Soft Clay. The value of Young's Modulus and Poisson's Ratio for these soils were taken from “(Das 1990)” [1], (see Table 1)

6. METHOD

Nine design runs were carried out as shown in Table 1

Run No.	Depth (m)	PHI Angle	Young's Modulus (MPa)	Poisson's Ratio	Foundation Soil Type
1	5	30	18	0.25	Medium Dense Sand
2	5	28	10	0.20	Compact Silty Sand
3	5	25	2	0.20	Soft Clay
4	10	30	18	0.25	Medium Dense Sand
5	10	28	10	0.20	Compact Silty Sand
6	10	25	2	0.20	Soft Clay
7	15	30	18	0.25	Medium Dense Sand
8	15	28	10	0.20	Compact Silty Sand
9	15	25	2	0.20	Soft Clay

Table 1. Foundation Soil Properties

7. RESULTS and OBSERVATIONS

The results of the analysis are plotted in graphs of moment versus directrix. When the foundation type remains constant and the depth is varied from 5 to 15 m for all three soil types, we observe that the moments increase as the depth increases. We also note that the moment increases as the soils bearing capacity ability decreases.

It should be mentioned that the moment diagram is not symmetrical about the crown. The Aztech program applies the backfill layers first on the right side then on the left, which results in a higher moment in the right arch element (see Figure 3a, b, and c).

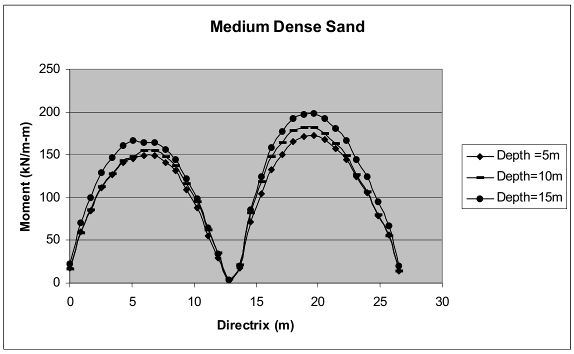

Figure 3a. Soil Type Constant (Medium Dense Sand) and Depth Varies

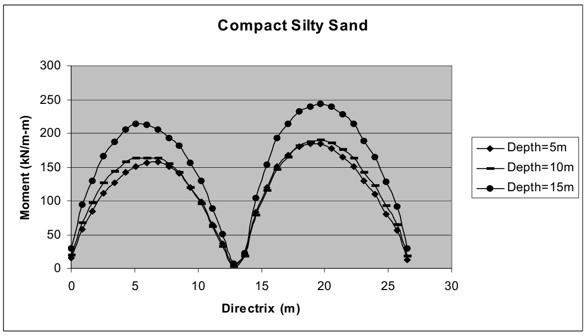

Figure 3b. Soil Type Constant (Compact Silty Sand) and Depth Varies

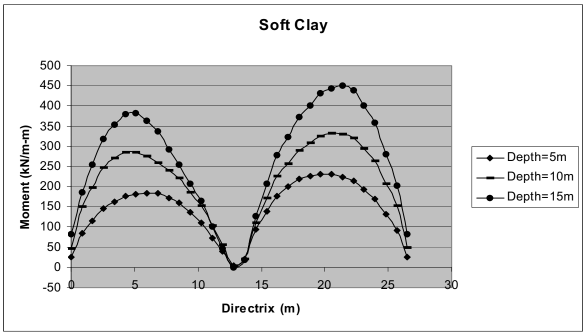

Figure 3c. Soil Type Constant (Soft Clay) and Depth Varies

As seen in the next three graphs when the foundation depth remains constant and the soil type is varied, we observe that the moments increase as the compressibility of the soil increases (see Figure 4a, b, and c).

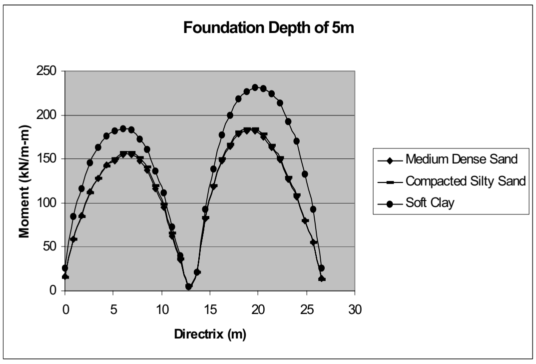

Figure 4a. Depth Constant (5m) and Soil Type Varies

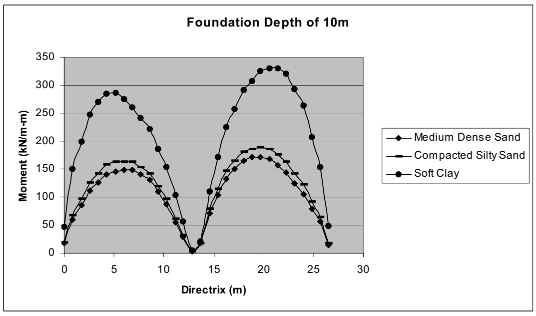

Figure 4b. Depth Constant (10m) and Soil Type Varies

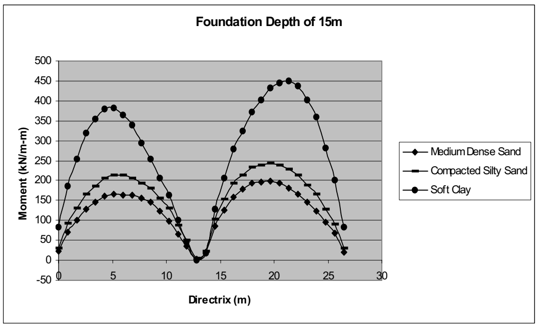

Figure 4c. Depth Constant (15m) and Soil Type Varies

The above results confirmed the authors' intuition that for increased depths and decreased stiffness of foundation soils the moments increased in the arch. In simple terms this is due to the "down-drag" force which the backfill on either side of the arch exerts on the arch.

The next step was to examine the effect that the settlement of the foundation soil has on the moments in the arch. The settlement value used represents the differential settlement that occurs between the pile cap, (which doesn't settle) and the soil adjacent to the pile cap but some distance away. (see Figure 5) There is a very strong and linear correlation between this settlement and the maximum moments in the arch. (see Figure 6) It can be said that regardless of the cause for differential settlement the effect is the same i.e. higher moments in the arch.

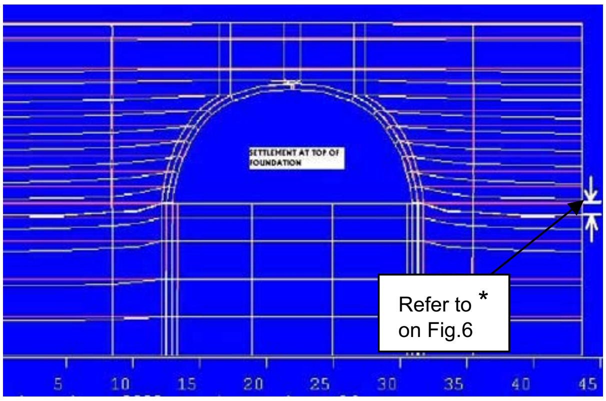

Figure 5. FEM Mesh Diagram - Settlement at Top of Footing

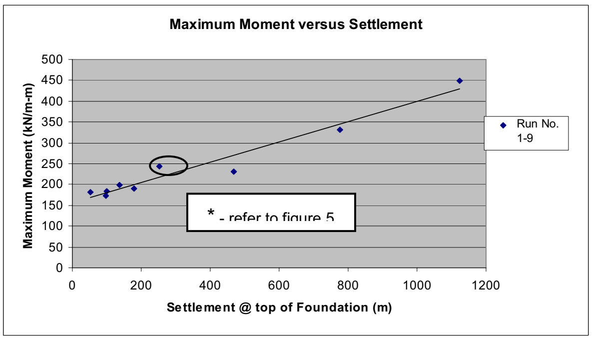

Figure 6. Maximum Moment versus Settlement on Top of Footing

8. A CASE HISTORY OF A TECHSPAN ARCH ON PIPE FOUNDATION

8.1 Description

In 2003 New York State Department of Transportation (NYSDOT) constructed a double-barreled pre-cast concrete segmental TechSpan™ arch on a pile foundation in Jamestown, New York. The underlying soil foundation indicated a very soft to stiff gray silty clay was present some 5.0 meters under the proposed footing location. From the bore holes, this soft material extended quite deep and NYSDOT concluded that a pile foundation was required.

Increased moments in the arch were included in the design as a result of the downdrag forces. The following elevation drawing (see Figure 7) and photo (see Figure 8) and show the proposed and completed structure respectively.

9. CONCLUSION

Buried concrete arches have been successfully built on piled foundations where poor underlying soils are present. Although it may be easliy assumed that the poor foundation soils are not of any concern for these types of structures on piles, the data and design runs in this paper proves the contrary. In fact the depth and stiffness and compressibility of foundation soils have a large effect on the loads, in particular the bending moments the arch will experience. It can be concluded that as the strength of foundation material decreases, the applied moments in the arch increase and as the depth of the foundation soil increase the moments increase as well.

Foundation soil information is critical in buried arch design even if the structure is on piles.

10. REFERENCES

1. (Das, R.M., 1990) "Principles of Foundation Engineering" PWS-Kent Publishing Company.

11. BIBLIOGRAPHY

Brockbank, B., Dunphy, R., and Yasinko, L. 1994. Innovative Underpass for Highway 63, Syncrude, Alberta. International Road Federation Conference and Exposition Proceedings, Volume 9,.Alberta, July, 1994

Brockbank, William J. and Segrestin, Pierre. 1995. Precast Arches as InnovativeAlternate to Short Span Bridges. Fourth International Bridge Engineering Conference. San Francisco, California, USA.

Duncan, J.M., Byrne, P., K. Wong and P. Mabry. 1980. Strength, stress-strain and bulk modulus parameters for finite element analysis of stresses and movements in soil masses. Report No. UCB/GT/80-01. Department of Civil Engineering, University of California, Berkeley, USA

Jenkins, D.A. Analysis of Buried Arch Structures: Performance versus Prediction. Reinforced Earth Pty. Ltd, Somersby, NSW. Australia.

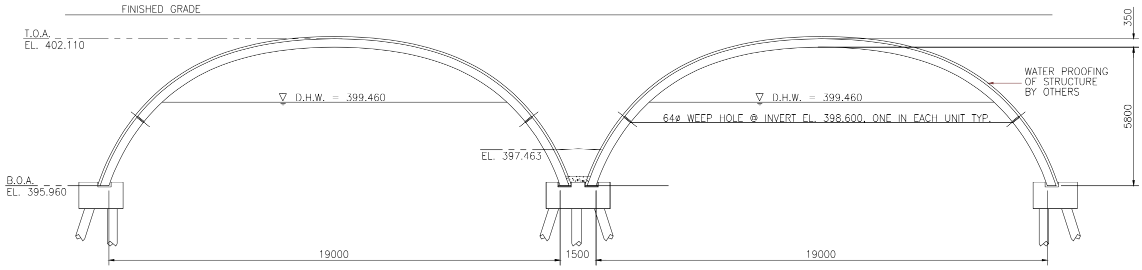

Figure 7. Elevation Drawing TechSpan Arch Structure on Pile Foundation

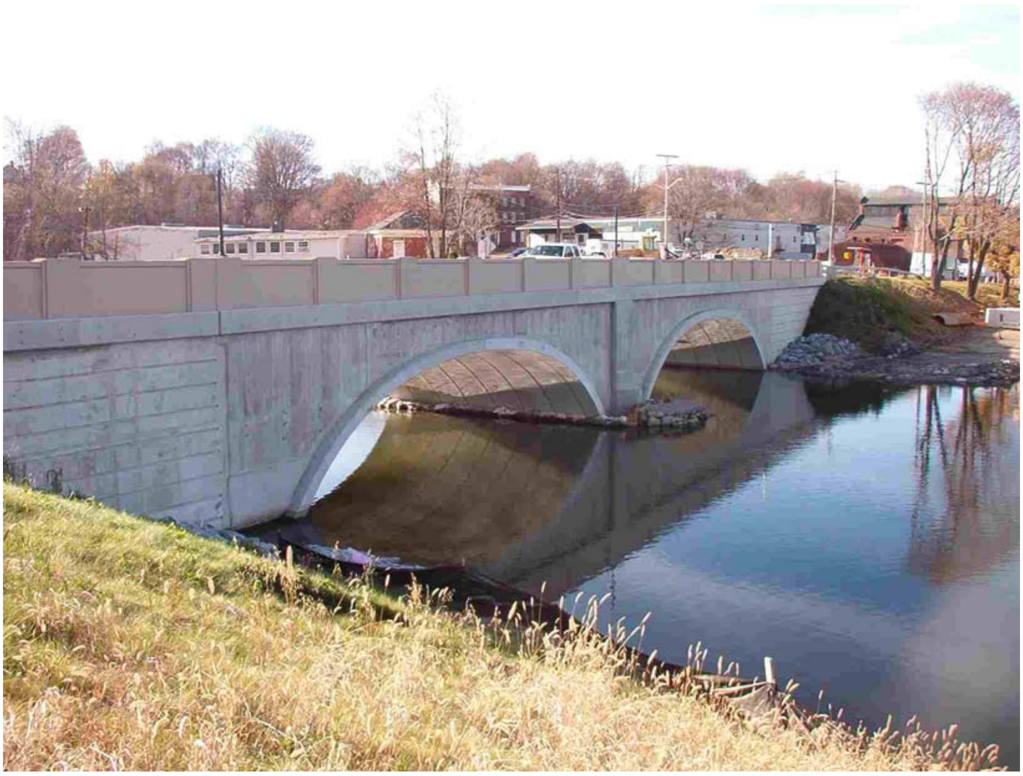

Figure 8. Completed TechSpan Arch structure on Pile Foundation
Jamestown, New York